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Patents ADP number (if you know it)

07628779001 (ndes)

If the applicant is a corporate body, give the country/state of its incorporation

ENGLAND

4. Title of the invention

COLOUR MONITORING

5. Name of your agent (if you have one)

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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

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YES

COLOUR MONITORING

The invention relates to colour monitoring.

5 PCT application WO 96/05489 describes a colour inspection system and method by which a video camera is controlled for the acquisition of a colour image under varying image capture conditions. A fast moving (approximately 500 metres min⁻¹) web of printed material
10 passing in front of the camera is monitored. The video camera of such a system has a red, green and blue output and is provided with a controllable iris aperture, a controllable overall RGB signal gain, independently controllable RGB signal channel gain, or a controllable
15 RGB signal channel balance. The controllable parameters are controlled by a control unit in the form of a personal computer having an image capture board. The personal computer generates signals from an image signal received from the video camera, the signals being used to correct
20 the controllable parameters to improve camera image capture performance.

The subject of the present application comprises an improvement to the system and methods described in the
25 aforementioned PCT application.

A first problem of the prior system and colour monitoring systems in general to be addressed by embodiments of the present invention relates to the
30 correction of camera output when used to monitor colours. In an ideal world, the video camera characteristic in terms of RGB output would be a linear characteristic so that zero light intensity from a completely black scene would give zero voltage outputs from a camera. Again, in
35 an ideal world, the RGB outputs would increase linearly

accordingly to increasing light intensity for a particular given colour. Unfortunately, real cameras exhibit an imperfect characteristic dependent upon ambient temperature giving an offset from the origin (i.e. a non-zero volt output for zero light intensity input), after
5 which there follows a generally linear response region which then, above a particular light intensity will tend to flatten out to give a non-linear response.

10 A second problem of the prior system to be addressed by embodiments of the present invention concerns the effects of non-uniformity of lighting characteristics across a material to be monitored. Again, in an ideal world, an unprinted stationary (or moving) material of
15 uniform colour and consistency when monitored by a video camera would appear as such. However, where colour monitoring is to be carried out, non-uniform lighting can cause the camera monitor to perceive different parts of the camera field of view (which typically may be of an A4-sized area) to have a different colour or different
20 lightness value. Ambient lighting by its nature is non-uniform both spatially and temporally and is therefore inappropriate for colour monitoring. A pure flash lighting of the web during colour monitoring procedures is
25 generally used but even this has problems due to reflections within the lighting (monitoring) enclosure and flash to flash intensity variations. Also, the physical characteristics of the monitored material itself and the variation in angle of lighting on the material across the
30 field of view means that different parts will reflect incident light to different extents, and this is further dependent on where the lighting source is positioned. In other words, the material will not only reflect incident light but also transmit it to a degree and, since it is
35 reflected light which the camera actually monitors (which

will include reflections from the monitoring enclosure itself subsequently passing again through the translucent material), a uniform coloured piece of material may be interpreted by a camera as being of non-uniform colour/
5 lightness because of the type and angle of the light sources, positioning of the camera, type of enclosure and composition of the material itself.

10 A third problem which has been encountered in colour monitoring is that the print design sometimes contains areas of "half-tone" and "vignettes" - i.e. areas of non-uniform colour, which nevertheless need to be checked for consistency through the print run, and in subsequent runs. To do this, the same area in the repeat must be inspected
15 with high spatial accuracy. In prior systems, triggering of image capture and lighting is typically done by registration marks located, for instance, at regular intervals and to one side of the web. When a registration mark is detected by a sensor, both the illuminating flash
20 is triggered and image capture carried out in a synchronized fashion. This type of triggering is advantageous in normal situations in that even if the speed of the web is inconsistent, triggering based upon web positions will always result in a consistent image
25 capture of a particular part of the web. In this context, it must be appreciated that in most situations, the printed web is likely to be a complex mix of colours which need to be accurately monitored, but which also have a given repeat length. By carrying out the aforementioned
30 type of triggering with registration marks appropriately positioned with respect to the cameras field of view and the repeat length, it can be ensured that the colour monitoring is always done consistently with regard to the web repeat. However, using registration marks in the
35 conventional manner, the high spatial accuracy required

for consistent checking of specific areas is not achievable. Neither can this conventional type of system cope with print webs which do not have a consistent and predictable repeat length. Also, in high speed web operation, it is not uncommon for the web to shift sideways by a few centimetres between repeats and this also causes problems with the conventional image capture method.

With a view to solving or reducing the first problem mentioned above, there is provided a method of calibrating a colour monitoring system so as to compensate for non-linear real camera characteristics, the method comprising:

establishing a camera offset by measuring or calculating the output voltage of the camera when substantially no light falls on any of its sensor elements, hereinafter referred to as establishing the offset;

establishing the point at which a graph of input light intensity against camera output voltage starts to deviate from a substantially linear characteristic, hereinafter referred to as establishing the knee; and

restricting the amount of light incident on all sensor elements of the camera such that the output corresponds to a voltage at, or below, the knee, and lower light intensities are all within the range of linear operation.

The step of establishing of camera offset must be done sufficiently frequently to keep pace with the variations in offset value caused by ambient conditions.

Preferably, the step of establishing offset is carried out whenever an image capture operation is to be carried out.

5 Setting the point of zero light intensity may be achieved by closing the camera iris. Alternatively, it may be achieved by setting the camera to monitor a black image, or a black part of an image. Alternatively, this may be achieved by extrapolating from measurements
10 obtained from two or more tiles of known reflectance somewhere in the image, for instance, this may be an integral part of the image itself or a white reference tile.

15 This has the advantage that it may be done for every image captured.

 A source of maximum light reflectance may be achieved by ensuring that a white object is present somewhere in
20 the image.

 Restricting the camera to operate within the linear region may be achieved by reducing the camera aperture by closing the iris to a predetermined degree such that the
25 output voltage when measuring the source of maximum light intensity corresponds to a camera output voltage at or below the knee.

 In practice, it is found with preferred embodiments
30 that for a typical camera, the iris may be restricted so as to give an output voltage to 175/255 of full scale to ensure that a perfect white reflector registers at the top of the linear region and to then scale down to find appropriate values of camera output versus light
35 intensity.

Preferably, the step of establishing the knee is carried out less frequently than the step of establishing the offset and may be carried out before commencing and/or after completing a plurality of print runs each comprising a plurality of image capture operations.

With a view to solving or reducing the second problem mentioned above, there is provided a method of compensating for non-uniformity of lighting across a camera field of view when performing an image capture operation to be monitored by the camera, the method comprising:

positioning substantially uncoloured or uniformly surface coloured material of known colour characteristics in a field of view of the camera; and

capturing image data from the camera and storing such captured image data as a "uniformity image" in memory the image data of the uniformity image including information concerning the degree of light reflected from the different spatial areas of the material detected by the camera.

By utilizing image data from the camera relating to the known coloured material, differences in data from the different parts of the field of camera view are attributable to the non-uniformity of lighting. Using this position related data, subsequently captured image data can be adjusted to be corrected for this positional effect.

In accordance with the method, image capture operations of images to be inspected are thereafter carried out and compensation for non-uniform lighting

conditions effected for each captured image. The compensation may comprise normalising each newly captured image across the camera field of view by determining spatial adjustment factors from the uniformity image and, where no uniformity image data is available for a particular spatial location, interpolating between the various positions or extrapolating beyond them.

The step of normalising image data may comprise the sub-steps of: recording output data from the camera averaged over all the pixels in a given spatial area of the sample with the sample at a first, training, position on the printed web to give first position camera channel output data C_T ; and recording the camera output data from the camera averaged over all the pixels in the same given spatial area of the sample with the sample at a second position on the printed web having different lighting conditions to give second position camera channel output data C_S .

The step of normalizing may comprise normalizing the second position camera channel output data C_S prior to comparing them to the trained values from the first position camera channel output data C_T by processing them in accordance with the following equation: $C_S \times C_1/C_2$, where C_1 is the average channel value for the area of the unprinted web corresponding to the first position, and C_2 is the average channel value for the unprinted web corresponding to the second, differently lighted position.

Preferably, three camera channels R, G and B (red, green, blue) are present such that, for instance, for the red channel R, the first position camera channel output data is R_T , the second position camera channel output data is R_S , the average red value for the area of the unprinted

web corresponding to the starting position is R_1 and the average value of the unprinted web corresponding to the second, differently lighted, position is R_2 .

5 The geometry of the illumination source and the camera must be such as to avoid specular reflections in both the "uniformity image " and the printed web image.

10 Operation must be made in the linear region of the camera channel and using the correct current offset.

15 Both the method of the first and second aspect, would in practice, be carried out for each of the individual camera channels (for instance, red (R), green (G) and blue (B)).

20 With a view to solving or reducing the third problem mentioned above, there is provided a method for the capture and analysis of image data of a moving material monitored by a camera having its field of view trained on the material, the method comprising:

25 storing a pattern recognition model comprising image data corresponding to at least part of a pattern repeat printed on the monitored material;

30 measuring the displacement of the pattern model in each captured image of the printed web to sub-pixel accuracy; and

35 calculating the colour of the displaced vignette or half-tone area allowing for sub-pixel displacements (both vertical and horizontal).

35 The method may further include the steps of:

monitoring synchronization signals (SYNC) from the camera; and

5 in accordance with the operating characteristics of the camera, triggering a lighting source during the camera vertical blanking interval so as to illuminate the material during image capture periods.

10 As will be appreciated from the above, capture of image data according to this aspect of the invention is based upon recognising the presence and position of the particular pattern model in a captured image during subsequent image processing rather than by triggering image capture upon the web achieving a particular position. The method may therefore be regarded as, and will be referred to as, an "opportunistic triggering" technique. In this way, the sub-pixel inspection method also facilitates the use of a normal video camera as opposed to a specialist camera system. Image capture may take place at time intervals which can be externally monitored by looking at the camera SYNC signals and illumination of the web at the appropriate moments can be triggered by the SYNC signals. The major advantage in performing image capture in this way, is that an ordinary video camera, as opposed to a higher cost image capture system, may be utilised. However, it will be appreciated that a triggerable camera may still be used with this method.

30 Preferably, image data from the camera is analyzed so as to carry out a pattern recognition operation based upon the pattern recognition model to determine the physical position of the printed pattern repeat on the web in the field of view of the camera at the time of image capture.

Following successful pattern recognition, analysis of the image captured to inspect the required areas displaced by the same displacements as the pattern model may be carried out with sub-pixel accuracy.

5

Preferably, the opportunist triggering technique is utilised in conjunction with the lighting non-uniformity compensating method which is also to be carried out to sub-pixel accuracy.

10

Specific embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

15

Figure 1 shows in schematic form a colour monitoring apparatus;

20

Figure 2 is a schematic graph showing camera output in volts, against input light intensity;

25

Figure 3 is a schematic diagram showing a graduated grey scale which may be incorporated within an image to be captured for ascertaining camera response;

Figure 4 shows a black tile and a white tile forming part of a test image;

30

Figure 5 illustrates how readings corresponding to the black tile and white tile of Figure 4 may be used to determine a camera offset;

35

Figure 6 is a schematic diagram showing possible relative size of repeat length with respect to size of field of view;

Figures 7A to 7C show respectively first to third patterns to be printed by first to third cylinders and to be monitored using an opportunistic triggering technique;

5 Figures 8 and 9 show respectively a training image and a newly captured image; and

10 Figures 10A and 10B show a perimeter area of a displaced image which it is desired to inspect to sub-pixel accuracy.

Referring to Figure 1 of the accompanying drawings, there is shown a typical set of apparatus which may be used for colour monitoring. The apparatus comprises an interface unit for interfacing to a conventional commercially available video camera 1, having a red, green, blue output (RGB output) and having a controllable iris aperture, a controllable overall gain, independently controllable RGB signal channel gains, or a controllable signal channel balance. The interface comprises an RS232C bus 2 to enable remote control of the camera and a conventional commercially available personal computer 3 having a conventional commercially available image capture board 4. The camera 1 is positioned within a lighting box 5 which also contains a flash lighting source 6. A trigger circuit 7 is provided which is connected to the camera output 1, to the lighting source 6 and to the image capture board 4 and to the PC 3. A monitor 8 is also provided.

30

The computer is adapted for control of the camera via the RS232C data bus, by means of a dedicated application programme. The dedicated application programme may form part of a larger computer programme, or may be run in conjunction with other application programmes.

35

Aspects of the present invention are primarily directed towards improving the usability of such a system by addressing the problems of non-linearity of camera characteristic, non-uniformity of lighting of a specimen to be monitored and triggering image capture by a simple method using the synchronisation signals (SYNC) generated in the normal course of events by the conventional video camera.

Concerning the first problem of non-linearity of camera characteristics, an embodiment of the first aspect of the present invention will now be described with reference to Figures 2 to 5.

Figure 2 shows a typical camera characteristic in terms of increasing light intensity of a known colour (R, G or B) along the horizontal axis and measured R, G or B output in volts along the vertical axis.

The graph of Figure 2 may be obtained, for instance, by capturing the image of a collection of paint chips of graduated colour, such as the grey scale 30 shown in Figure 3. All paint chips must be captured in a single image capture period and under uniform illumination.

The known colours can be measured using established colorimetric techniques, i.e. a colorimeter or spectrophotometer traceable to national colour measurement standards, coupled with a standard conversion matrix to convert the CIE tristimulus measurements into camera R, G, B values.

Referring to Figure 3, the left most paint chip 31 is black, the right most paint chip 32 is white and, in between, are chips of intermediate shades of grey. The

images of each of those chips are captured to plot the graph of Figure 2. Note that the vertical axis may be any one of the measured R, G or B outputs and also that in obtaining this graph the iris of the camera 1 is set so that the white chip produces a near saturation R, G and B output, the horizontal axis represents increasing light intensity from black to white, in known increments as determined by the test pattern of Figure 3.

Referring to the characteristic plot of Figure 2, it can be seen that the graph is generally linear, but tends to flatten out above a knee point (K). Also, there is an origin offset (OFF). It will be seen that in the plot illustrated, the paint chip 32 representing the highest light intensity level, pure white (i.e. the most white) is shown as a plotted point 20 which falls within the non-linear region. The graph of Figure 2 also shows the next "nearest to white" paint chip as giving a plotted point 21 which is in the non-linear region.

In an ideal world, the camera characteristic would pass through the origin and be totally linear. However, as seen from the above, conventional video cameras do not operate in this ideal fashion and it is necessary to compensate for this non-linearity if accurate determinations of light intensity are to be made.

In order to provide an effective compensation, the offset (OFF) and the knee point (K) need to be determined.

To complicate matters more, camera characteristics including the offset change by measurable amounts as the camera 1 warms up and cools down, and as ambient temperature changes. So for accurate colour monitoring

purposes, compensation needs to occur by varying amounts every time an image is captured.

5 In order to determine the offset, a black object
(zero reflectance) may be included in the image at each
image capture point. By analyzing the output data from
the camera relating to the black object area of the image,
the average corresponding R, G and B output values may be
found and those values can be directly taken as the offset
10 values for the respective R, G and B channels.

The drawback with this approach is that it is
difficult to get a perfectly black object, and to make
sure that it picks up no contaminant prior to being
15 monitored that changes its colour. In view of this, a
better approach is to use a white ceramic tile 40 (see
Figure 4) of known RGB, and a black ceramic tile 41 of
known RGB simultaneously present within the camera field
of view 42 (the RGBs can be measured using a colorimeter
or a spectrophotometer traceable to national colour
20 measurement standards and by using a standard matrix for
converting those measurements to camera RGB values).
Ceramic tiles may be easily cleaned by using lens tissue
before image capture takes place.

25 Prior to using this black and white tile method, it
must be established that the camera is operating in a
linear fashion. This may be done by forming the graph of
Figure 2, restricting the size of aperture to avoid going
30 beyond the knee, and then repeating the graph measurements
to check that all of the points on the measured grey scale
now produce R, G, B outputs within the linear region. All
of the grey scale needs to be captured during a single
capture period (i.e. from a single image) under uniform
35 lighting conditions. Adjusting the voltage output to be

175/255 of full scale when inspecting white portions of the image will in practice, suffice in many practical situations as long as the whole field of view is uniformly lit or the white tile is in a sufficiently well lit part of the field of view that no part of the field of view produces above knee signals and may be used for all camera operations once it has been verified that the camera is indeed operating wholly within the linear zone.

10 Having ensured that the camera is being operated below its knee point, a graph as shown in Figure 5 may be obtained from the measured white tile and black tile by drawing a line between the two known points and extending that line to find the offset from the origin.

15 The two known points can be measured using established colorimetric techniques, i.e. a colorimeter or spectrophotometer traceable to national colour measurement standards and by using a standard conversion matrix for
20 converting these measurements to camera R, G, B values.

25 If it is ensured that the black and white tiles are permanently in the field of view, then the calculation of offset (by using the two points given by black and white tiles) may be done by the computer each time an image is monitored to provide reliable compensation for camera characteristics in real time situations.

30 An alternative for checking the offset is to close the iris of the camera and use the R, G and B average values with the iris closed, to directly determine the offset.

35 Turning now to the second problem of prior art systems which relate to non-uniformity of lighting

characteristics across the material to be monitored, preferred embodiments of methods for compensating such non-uniformity will now be described.

5 Non-uniformities in lighting, particular characteristics (e.g. internal reflections) of the lighting enclosure from which individual images are captured, and physical characteristics of the substrate material can all cause anomalies in the amount of
10 reflected light arriving at the camera lens from different spatial locations within the camera field of view and need to be compensated for.

15 The principle behind such a compensation technique is to capture an image of a uniformly coloured or uncoloured sample of material. Spatial image data from the unprinted web and incident to the camera lens embodies data concerning not only the uniformity of incident rays in different parts of the field of view but also the
20 translucency of the web and the internal reflections from the lighting enclosure.

25 It is known, of course, that the unprinted sample of material is, in fact, an essentially uniform surface. By detecting spatial non-uniformities in camera output over the field of view, normalising settings may be achieved, so that individual output data from individual spatial areas is compensated. For example, the average R, G and B of an area of surface colour are recorded at its
30 starting (trained) position, R_T , G_T , B_T . When the image is next captured, suppose this area in the design has moved to a less well-lit position and its average R, G and B are now R_s , G_s , B_s . If R_1 , G_1 , B_1 , are the average RGB values for the area of the unprinted web corresponding to the
35 starting position, and R_2 , G_2 , B_2 the average values of the

unprinted web corresponding to the less well-lit position, then R_s , G_s , B_s are normalized as follows before comparing them with the trained values R_T , G_T , B_T :

5 $R_s \times R_1/R_2$, and the same for G_s and B_s .

Concerning the third aspect, there will now be described how an opportunist triggering technique may be used to monitor a moving web of material without the need
10 for complex triggering methods.

Referring now to Figure 6, there is shown a typical web of material which it may be desired to monitor. Figure 6 shows schematically, the nominal field of view
15 seen by the monitoring camera and represented by rectangle 60 superimposed over a schematic view of moving web of material 61.

It will be appreciated that a pattern printed on the
20 web 61 will have a given repeat length R . The repeat length defines the pattern printed on the web in its entirety and may be wider (as shown here) or narrower than a width W of the field of view 60 of the monitoring camera.

25

In previous systems, if it was desired to monitor a full repeat of the web 61, or indeed to simply monitor known portions of the sampled web, a reference mark on the web could be used in conjunction with a sensor to trigger
30 an image capture cycle when the web has reached a particular point. In such systems, image capture is driven by the positioning of the web, and the image capture system must be ready to fire whenever the reference mark aligns with the triggering sensor. To

implement such systems, the monitoring camera needs to be of a relatively sophisticated nature.

5 Embodiments of the present invention tackle the problem of triggering in a different fashion.

10 In embodiments of the present invention, a basic video camera may be used and image capturing driven by synchronisation (SYNC) signals from the camera itself.

10 According to the method, a particular unique feature within the full repeat (R) has its image data pre-stored in memory, so that it may be used for pattern recognition purposes. With the web of material running,
15 synchronisation signals output from the video camera are monitored and lighting and image capture from the web triggered in accordance with the synchronisation signals, so that whenever the camera itself is ready to perform an image capture operation, and such an image capture
20 operation is called for, lighting of the web is automatically synchronised and carried out on the basis of the SYNC signals.

25 Once an image capture operation has been performed, it is necessary to determine what the image is of. In that regard, the captured image data is analyzed using a proprietary pattern recognition programme, so as to determine exactly what the image is of, in relation to the unique feature in the pattern repeat. Thereafter, once
30 the system knows exactly what the captured image data is of, standard colour monitoring procedures may be carried out to monitor quality of printing etc. and utilising any other software compensation techniques with regard to non-linearity compensation/non-uniformity of lighting
35 compensation etc. to determine meaningful results.

A typical mode of operation of the apparatus of the present invention will now be described.

5 With unprinted web material present and with the aperture restricted (if required) to ensure operation in the linear range of the camera characteristic, an image is captured in order to perform the lighting uniformity compensation referred to earlier. Such a "uniformity image" is then captured for a 350 mm field of view, or if
10 a 205 mm field of view is to be used a separate uniformity image is captured for this.

15 Thereafter, with the approved printed material running on the press and with white and black reference tiles present, an image is captured. The reference tiles serve to enable an accurate determination of slope and offset of the camera characteristic during each capture operation as described previously and the white tile also serves to control the camera and keep the colour
20 measurements repeatable as described in PCT application W096/05489. Rectangles may be drawn over particular areas of the pattern to be monitored. A sufficient number of images are captured, in order to record details of the full repeat.

25 Next, a training operation is carried out. Training does the following: it automatically selects a pattern model and trains the colours, using lighting uniformity compensation and any other required software adjustments.
30 The system may then be set to what is known as an "auto-inspect" mode, in which it will monitor the colours of the areas defined by the rectangles in the training image at ten second intervals throughout the run, giving real-time and logged results. Auto-inspect does the following:
35 captures an image every ten seconds from the moving web,

keeping the camera controlled; finds the pattern model and calculates image displacement from a trained image; inspects the coloured areas, allowing for the displacement and lighting uniformity; logs the results to file; and
5 signals if the colour of any area is beyond warning limits.

During such automatic inspection, the training image will be displayed at all times and the ongoing
10 measurements of any defined area may be displayed at will.

It has been discovered that this opportunist triggering technique produces a distinct advantage over traditional web-triggering in applications where the print
15 cylinders are not in register with each other.

For example, in the printing of filter-tip cigarette paper where it is desired to print a cork design on the paper in a seemingly random fashion there is illustrated
20 in Figures 7A to 7C a pattern to be printed by means of three cylinders.

The first cylinder shown in Figure 7A is utilised to print a manufactures mark 70 (LOGO). The mark (LOGO)
25 needs to be printed once per cigarette.

The second cylinder shown in Figure 7B is used to print a first colour 71, for example a solid yellow 11. The third cylinder shown in Figure 7C is utilised to print
30 a further pattern 72, for instance a brown colour with gaps formed in it to allow the yellow to show through those gaps. Prints 71 and 72 together form the cork design.

The mark 70 must be printed on every cigarette, but the filter tip design, made up of the first colour 71 from cylinder 2 overlaid by brown from cylinder 3, must appear random, so its repeat is say 3.5 cigarettes.

5

Each cylinder further prints a rectangular box 73-75 at the edge of the web showing its ink colour once per cylinder circumference as well as a text string 76, 77, 78.

10

Because it is desired to produce a non-regular pattern there is no requirement for the cylinder to have the same circumference, nor for them to rotate in phase with each other. The ink boxes therefore appear at random relative to each other, and this causes problems in web-triggered inspections systems.

15

Because it is the colour of the ink boxes which is to be monitored, and because each ink box is a fixed distance from its associated text string, the problem with regard to web-triggering which was encountered in the prior art may be removed altogether by the use of the opportunistic triggering techniques described previously. This is achieved by using the unique text string 76-78 which accompanies each ink box 73-75 as a pattern model, and searching can be done every captured image for all 3 text strings, to thus find the ink boxes 73-75 and then inspect their colour.

20

25

30

Referring now to Figures 8 and 9, there is illustrated a method for inspection of an area of a web of material to sub-pixel accuracy.

35

Figure 8 shows a camera field of view with a web of material 80, on which there is printed a logo 81 and other

image data 82 including an inspection area 83. The view shown in Figure 8 is, for instance, an original training image used during setup.

5 Figure 9 is an image captured during a subsequent image capture cycle and featuring the same elements as the image shown in Figure 8. In Figure 9, it will be noted that the web has been displaced to the right of the field of view by an amount and that the actual positioning of
10 the design is vertically displaced. This vertical displacement can occur due to triggering inaccuracy or may occur as a result of the use of an opportunistic type triggering method as previously described.

15 The element 81 referred to above as the pattern model whose data is stored from the original training image is used as a search pattern to locate the same pattern in the captured image. Once that design has been located in that captured image, its displacement can be calculated which,
20 for instance, may be 50.6 pixels to the right and 73.3 pixels down. Knowing the displacement of the pattern model, the area to be inspected 83 can also be located by using the same displacement, i.e., it will be known that that area is also 50.6 and 73.3 pixels displaced relative
25 to its original position.

 In the newly captured image, a rectangle of pixels may be processed which is slightly larger in area than the original inspection rectangle in the training image and a
30 margin of error given by adding an extra row and an extra column of pixels. Because the displacement involves pixel fractions, the area of the design to be inspected now straddles pixels. Here, the assumption is made that the digitised value of the voltage level corresponding to 0.1
35 pixel corresponds to 0.1 of the digitized value of the

voltage level for that entire pixel. In order to measure the average R, G or B values of the area, a fraction of the pixel values around the perimeter is taken as follows:

5	Top left corner take $0.4 \times 0.7 \times R, G$ or B value of this pixel
	Top right corner take $0.6 \times 0.7 \times R, G$ or B value of this pixel
	Bottom left corner take $0.4 \times 0.3 \times R, G$ or B value of this pixel
	Bottom right corner take $0.6 \times 0.3 \times R, G$ or B value of this pixel
	Top row of pixels take $0.7 \times R, G$ or B of all these pixels
10	Bottom row of pixels take $0.3 \times R, G$ or B of all these pixels
	Left row of pixels take $0.4 \times R, G$ or B of all these pixels
	Right row of pixels take $0.6 \times R, G$ or B of all these pixels

15 Add the R, G or B of each pixel in the displaced area, and the R, G or B of each straddling pixel, weighted as shown in the above table. Divide the grand total by (width x height), and this gives the average R, G or B of the inspected area to sub-pixel accuracy. Each of the channels R, G and B must be processed independently.

20

To explain the above further, Figures 10A and 10B are referred to.

25 Figure 10A shows a training image together with a inspection area 83 to be inspected and marked with a rectangle A (shown as -----). Each illustrated "square" represents a pixel and the inspection area necessarily encompasses whole (integer) pixels. Note that an unrealistically small inspection area of 5×5 pixels is shown here so as to enable pixel fractions to be demonstrated. Actual inspection areas used would in practice be very much larger in area.

30

Figure 10B shows a captured image with the inspection area 85 displaced by 50.6 pixels in the horizontal (x) direction and 73.3 pixels in the vertical (y) direction.

5 For the purposes of the following discussion, it is of course evident that to illustrate the boundary conditions, an actual displacement of 50 x 73 cannot be shown in Figure 10B. Rather, Figure 10B is used solely for the purposes of discussing what happens at the
10 subpixel level. The square A containing inspection area 83 of Figure 10A is shown in Figure 10B as having moved to position A'. The "floor" integer pixel position, i.e. the pattern model shifted by 50 pixels horizontally and 73 pixels vertically is marked as rectangle C (shown _._._.).

15 In the Figure, Δx = fractional pixel horizontal displacement (+VE meaning displacement to the right); Δy = fractional pixel vertical displacement (+VE means displacement in a downward direction); x-displ = integer part of horizontal displacement; y-displ = integer part of
20 vertical displacement.

In the example given, $\Delta x = 0.6$, $\Delta y = 0.3$, floor x-displ = 50, floor y-displ = 73.

25 If Δx and Δy are positive, a column of pixels to the right of the displaced area and a row of pixels below the displaced area are processed. If Δx and Δy are, on the other hand, negative, a column to the left and a row above
30 are processed.

The same equations for calculating the fraction of each pixel in the bottom, top, left and right rows and columns in the extended processing area are used whether
35 Δx and/or Δy happen to be positive or negative (+VE or -

VE). In otherwords, concerning the perimeter area for the example shown in Figures 8/9 and the displacements of which are illustrated schematically in Figures 10A and 10B, the fractional pixel values providing the weighting as given in the table 1 are shown as shaded areas in Figure 10B and are obtained by performing the following calculations:

- (i) Top left hand corner pixel = $(1-\Delta y) (1-\Delta x)$ x R, G or B pixel value
- (ii) Top right hand corner area pixel = $(1-\Delta y) (\Delta x)$ x R, G or B pixel value
- (iii) Bottom left corner pixel = $(\Delta y) (1-\Delta x)$ x R, G or B pixel value
- (iv) Bottom right corner pixel = $(\Delta y) (\Delta x)$ x R, G or B pixel value
- (v) Top row of pixels = $(1-\Delta y)$ x R, G or B pixel value
- (vi) Bottom row of pixels = Δy x R, G or B pixel value
- (vii) Left row of pixels = $(1-\Delta x)$ x R, G or B pixel value
- (viii) Right row of pixels = Δx x R, G or B pixel value

Again, when inspecting these perimeter values the assumption is made that the digitized value of the voltage level corresponding to 0.1 pixel corresponds to 0.1 of the digitized value of the voltage level for that entire pixel.

By referring to the above, it may be seen that there is provided a method for inspection of an area of a web of material to sub-pixel accuracy which facilitates web

inspection even when parts of the design on the entire web appear to vary in a seemingly random fashion.

5 The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

10

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

15

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

20

25

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

30

1/6

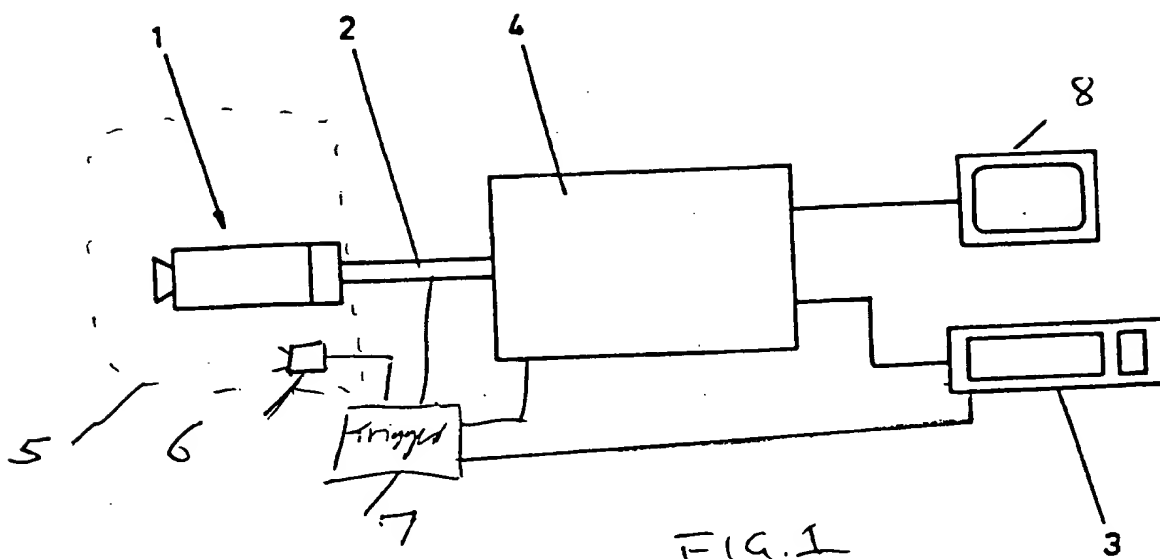


FIG. 1

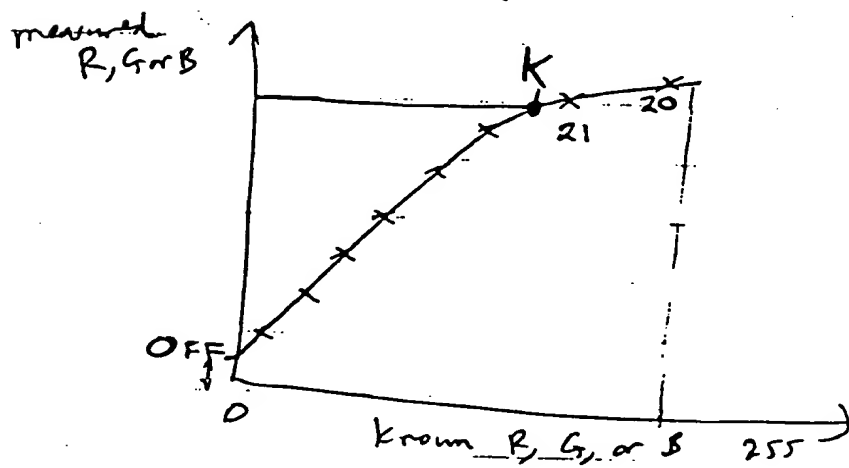


FIG. 2

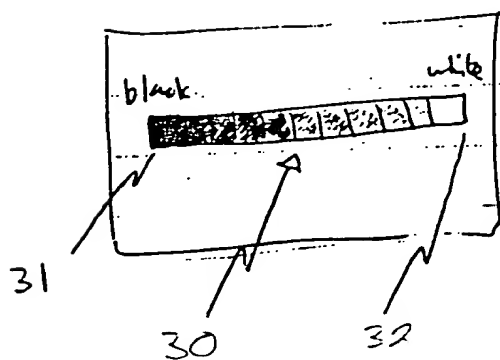


FIG. 3

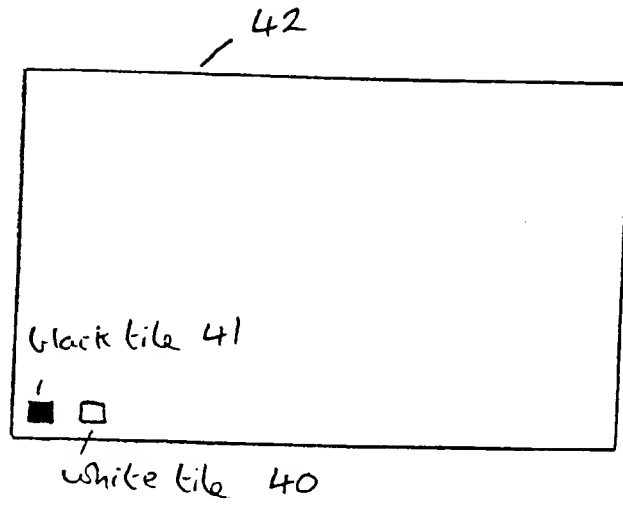


FIG. 4

Measured
R, G or B

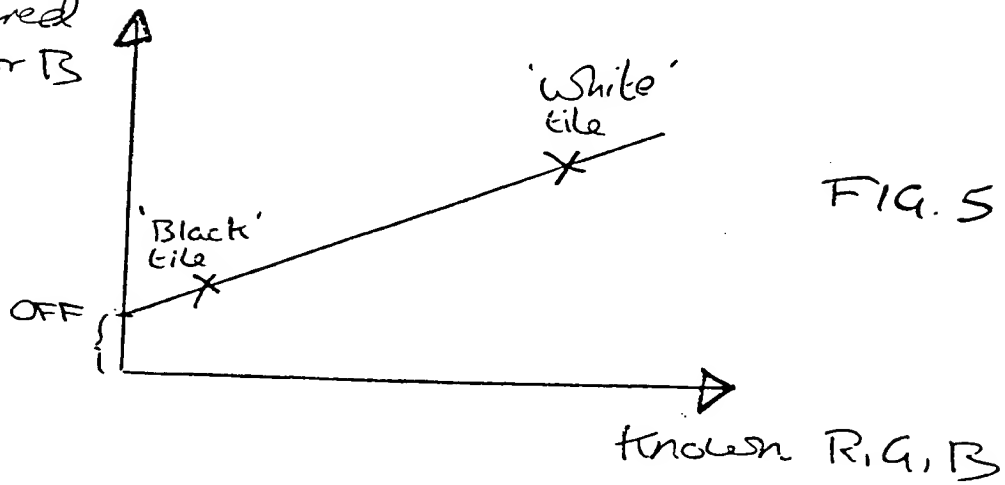


FIG. 5

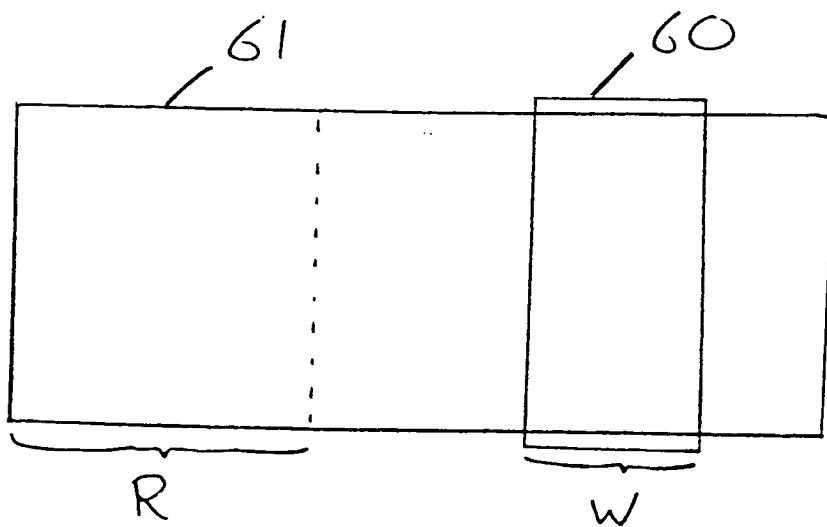


FIG. 6

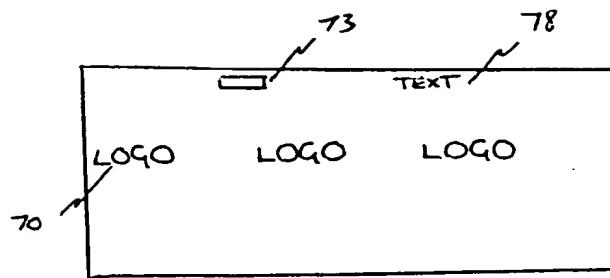


FIG. 7A

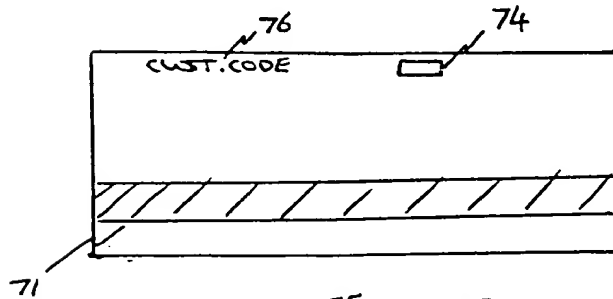


FIG. 7B

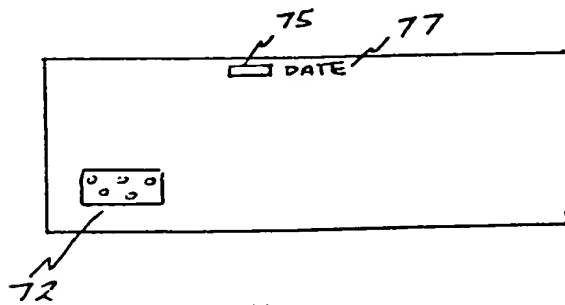
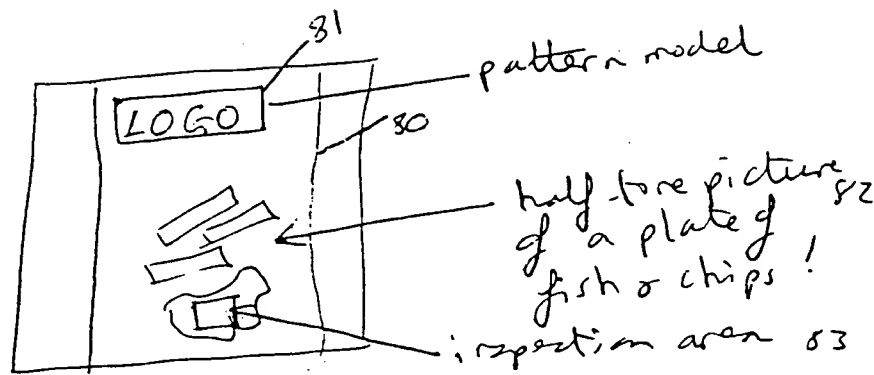


FIG. 7C

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original, training image

Fig 8

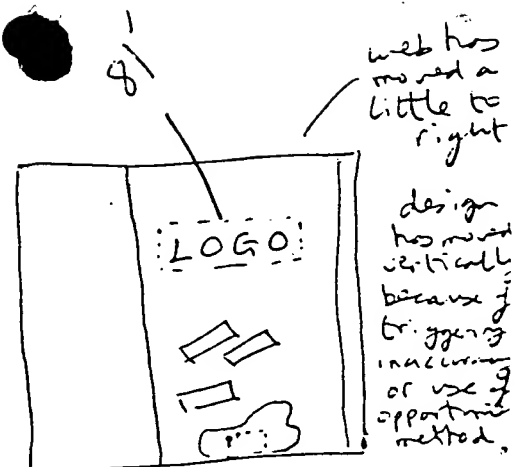
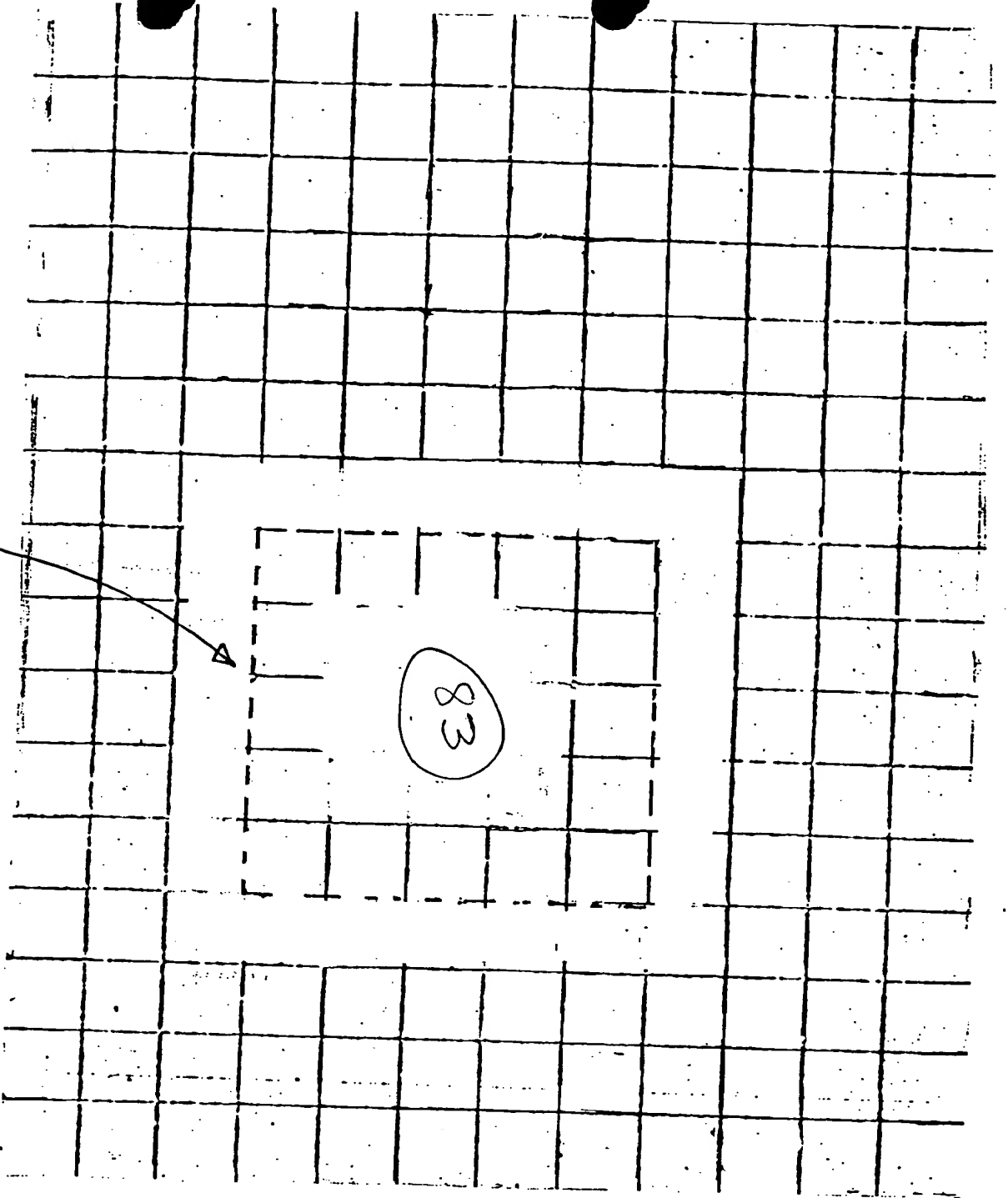


Fig. 9 newly captured image to be inspected

pattern model is found with sub-pixel accuracy and its displacement found - eg 50.6 pixels to right and 73.3 pixels down

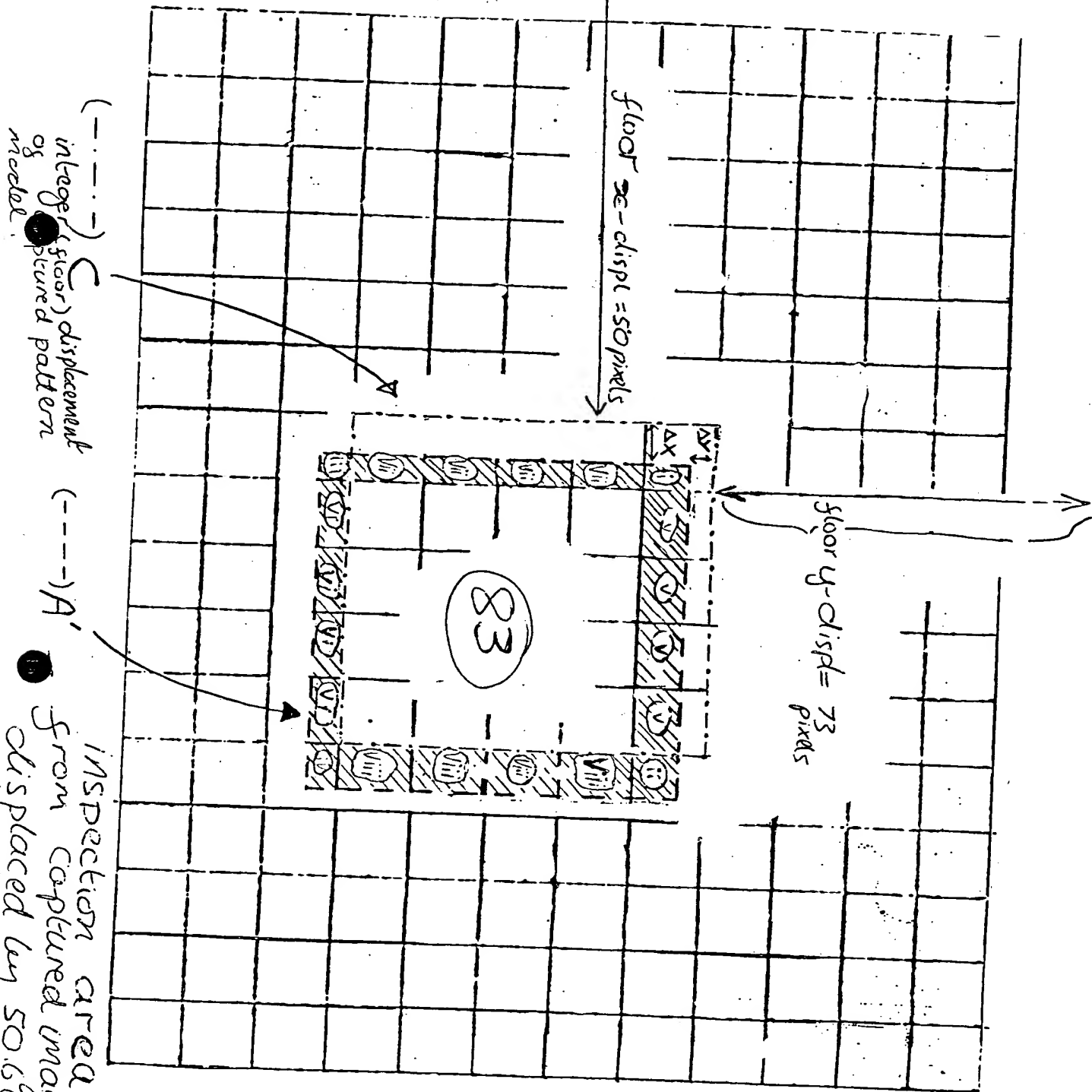
So the area to be inspected is also 50.6×73.3 pixels displaced relative to its original position.



"A" undisplaced training
image inspection area

FIG. 10A

FIG. 10B



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